4. b. Justification of BAT for each process stage in the integrated carbon capture process. As explained in your technical summary, the carbon capture abatement plant is a multi-stage sequential operation (enhanced kiln gas cleaning, LCP, SO3 scrubbing, wet ESP etc). If not addressed elsewhere in the BAT assessment, briefly justify that the technology choice made per step is BAT. It is likely that if a technique is recognized BAT in another similar sector/process/application/purpose (e.g. in EU BAT conclusions), then it will be considered BAT for your system.

Process area	**Equipment / Process**	**Purpose**	**BAT justification**
Pre-Carbon Capture Cement Plant	Waste Heat Recovery Unit (WHRU)	Energy efficiency	There are typically two options for WHRU to transfer heat from the cement process for use in power generation or as a heat source - low pressure steam or thermal oil. Heidelberg Materials have multiple Organic Rankine Cycle (ORC) power generation systems operational throughout the group using thermal oil as the heat transfer fluid. Thermal oil was chosen due to the experience and knowledge already available within the company. Thermal oil systems usually have lower capital (as the pipes tend to be smaller) and operating cost than steam systems as there are less consumables such as water treatment chemicals and staffing costs to monitor the operation of the steam system.
	Lime injection/addition	SO_2 control	Cement & lime BAT 1.5.3 a) SOx emissions: The SO_2 emissions from the cement kiln already meet the BATAEL for cement. However, SO_2 in the CO_2 absorber leads to high levels of amine consumption and therefore needs to be controlled to significantly lower levels. Absorbent is either added to the raw materials (e.g. hydrated lime addition) or injected into the gas stream (e.g. hydrated or slaked lime ($Ca(OH)_2$), quicklime (CaO), activated fly ash with a high CaO content or sodium bicarbonate ($NaHCO_3$)).
	Activated carbon injection	Hg control	Activated Carbon is injected as an adsorbent into the gas stream prior to the fabric filter. The activated carbon retains the mercury in the system, however, the concentration of mercury within the system increases. To break the cycle, some dust from the fabric filter needs to be removed. This is done periodically, and the dust is transferred to the cement milling process. See CLM_Bref_ adopted 1.3.4.7.1 Mercury for more detail.
Combined Heat and Power (CHP)	Natural Gas	Fuel supply for CHP	A waste to energy plant was investigated, this required more land area than was available at Padeswood. In addition, the capital and operating costs of a waste to energy plant were significantly higher than use of natural gas as fuel for the CHP.
	Low NOx burner	NOx control	LCP BAT 8.3 The technique (including ultra- or advanced low-NOX burners) is based on the principles of

			reducing peak flame temperatures; boiler burners are designed to delay but improve the combustion and increase the heat transfer (increased emissivity of the flame). The air/fuel mixing reduces the availability of oxygen and reduces the peak flame temperature, thus retarding the conversion of fuel-bound nitrogen to NOX and the formation of thermal NOX, while maintaining high combustion efficiency. It may be associated with a modified design of the furnace combustion chamber. The design of ultra-low-NOX burners (ULNBs) includes combustion staging (air/fuel) and firebox gases' recirculation (internal flue-gas recirculation). The performance of the technique may be influenced by the boiler design when retrofitting old plants. A low NOx burner is proposed for the CHP element of the Padeswood project.
	Burner management system	NOx and/or CO	LCP BAT 8.1 Advanced control system: The use of a computer-based automatic system to control the combustion efficiency and support the prevention and/or reduction of emissions. This also includes the use of high- performance monitoring. A burner management system is proposed for the Padeswood project.
	Steam turbine Generator (STG)	Power generation	Several options were considered for supplying the heat and power required to operate the capture plant, the steam turbine generator was selected because it had the lowest gas flow and highest CO2 concentration in the CHP exhaust gases thus reducing the size requirements for capturing CO2 from the CHP.
	Sodium Based solution (SBS) injection	$SO_{2\,/3}$ control	LCP BAT 8.4 A suspension/solution of an alkaline reagent is introduced and dispersed in the flue- gas stream. The material reacts with the gaseous sulphur species to form a solid which is removed with dust abatement techniques (bag filter or electrostatic precipitator). SDA is mostly used in combination with a bag filter. SBS with wet electrostatic precipitator is the combination proposed for the Padeswood project to minimise amine consumption.
	Selective catalytic Reduction (SCR)	NOx control	The NOx emissions from the cement kiln already meet the BATAEL for cement. However, NOx in the CO2 absorber leads to higher levels of amine consumption and therefore needs to be controlled to lower levels. Cement & lime BAT 1.5.2 d) NOx emissions: SCR reduces NO and NO2 to N2 with the help of NH3 and a catalyst at a temperature range of about 300 – 400 °C. This technique is widely used for NOx abatement in other industries. Selective non catalytic reduction, SNCR is not suitable after the CHP as the gas is below the required

			temperature window for SNCR. LCP BAT 8.3: Selective reduction of nitrogen oxides with ammonia or urea in the presence of a catalyst. The technique is based on the reduction of NOX to nitrogen in a catalytic bed by reaction with ammonia (in general aqueous solution) at an optimum operating temperature of around 300–450 °C. Several layers of catalyst may be applied. A higher NOX reduction is achieved with the use of several catalyst layers. The technique design can be modular, and special catalysts and/or preheating can be used to cope with low loads or with a wide flue-gas temperature window. 'In-duct' or 'slip' SCR is a technique that combines SNCR with downstream SCR which reduces the ammonia slip from the SNCR unit.
Quencher	Flue Gas Desulphurisation (FGD)	SO_2 control	SO2 in the CO2 absorber leads to higher levels of amine consumption and therefore needs to be controlled to significantly lower levels than those set for emissions from cement or Large Combustion Plant. Cement & lime BAT 1.5.3 b) SOx emissions: The wet scrubber is the most commonly used technique for flue-gas desulphurisation in coal-fired power plants. For cement manufacturing processes, the wet process for reducing SO2 emissions is an established technique. SOx are absorbed by a liquid/slurry which is sprayed in a spray tower. The absorbent is generally calcium carbonate. Wet scrubbing systems provide the highest removal efficiencies for soluble acid gases of all flue-gas desulphurisation (FGD) methods with the lowest excess stoichiometric factors and the lowest solid waste production rate. The waste water generated at this stage will be used in the mills of the clinker and cement processes.
	Wet Electrostatic Precipitator (ESP)	Particulate control	Particulate emissions from the cement kiln are controlled using a fabric filter and meet the BATAEL. Particulates entering the absorber can lead to increased amine losses and higher energy requirements in the solvent reclaimer therefore additional particulate control is required. Cement & lime BAT 1.5.1 Dust emissions LCP BAT 8.4 Technique or combination of scrubbing techniques by which sulphur oxides are removed from flue-gases through various processes generally involving an alkaline sorbent for capturing gaseous SO2 and transforming it into solids. In the wet scrubbing process, gaseous compounds are dissolved in a suitable liquid (water or alkaline solution). Simultaneous removal of solid and gaseous compounds

			may be achieved. Downstream of the wet scrubber, the flue-gases are saturated with water and separation of the droplets is required before discharging the flue-gases.
Carbon Capture (CC)	Absorber	CO2 capture	See justification for amine selection - Action 4a of not duly made letter
	Wash tower	Flue gas clean up	A separate wash tower will be installed consisting of a 3 stage wash. Both acid and water washes are included in the design. Acid wash is considered BAT
	Regenerator	Solvent recovery	The regenerator separates the solvent from the CO_2. The solvent is returned to the process for reuse and the CO_2 is metered prior to storage. Steam from the CHP is the source of heat for the regenerator.
	Reclaimer	Efficiency	The reclaimer handles the residual solvent recovered from the process and increases the overall efficiency of solvent recovery
Utilities & waste	Water treatment	Water quality	Process water for the current kiln operation is supplied from a borehole approx. 5km east of the works. The water required for carbon capture operations are significantly more than the volume of potable water available at Padeswood therefore a licence amendment to extract additional water specifically for the carbon capture process has been agreed with NRW. Irrespective of the water supply a water treatment plant was required to produce demineralised water and boiler feed water of the correct quality to maintain steady operation and prevent damage to the steam and power generation equipment
	Waste	Waste control	A philosophy of zero waste discharge has been key to the design. With that in mind, waste from the CC plant will be used in the kiln and associated processes as detailed in *Evidence Review of emerging techniques for Carbon Dioxide Capture Using Amine-Based and Hot Potassium Carbonate Technologies under the IED for the UK Ver.4.4, March 2024.*
	Waste water		The process has been to design to have "zero liquid discharge", to avoid the need for waste water treatment and discharge to surface water or sewer. High mineral content waste water from the water treatment plant will be used for evaporative cooling in the cement plant thus the mineral content (eg calcium oxide, carbonate or sulphate) will be part of the cement product.
	Compressed air	Energy efficiency	Compressed air being used as instrument air will be provided by energy efficient compressors.